ICCG-16 ABSTRACT

Meniscus Shapes in Detached Bridgman Growth

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Abstract

In detached Bridgman crystal growth, most of the melt is in contact with the ampoule wall, but the crystal is separated from the wall by a small gap, typically 1-100 micrometers. A liquid free surface, or meniscus, bridges across this gap at the position of the melt-crystal interface. Meniscus shapes have been calculated for the case of detached Bridgman growth in cylindrical ampoules by solving the Young-Laplace equation. Key parameters affecting meniscus shapes are the growth angle, contact angle of the meniscus to the ampoule wall, the pressure differential across the meniscus, and the Bond number, a measure of the ratio of gravitational to capillary forces. In general, for specified values of growth and contact angles, solutions exist only over a finite range of pressure differentials. For intermediate values of the Bond number, there are multiple solutions to the Young-Laplace equations. There are also cases where, as a function of pressure differential, existence intervals alternate with intervals where no solutions exist. The implications of the meniscus shape calculations on meniscus stability are discussed.

16th International Conference on Crystal Growth
Beijing, China
August 8-13, 2010

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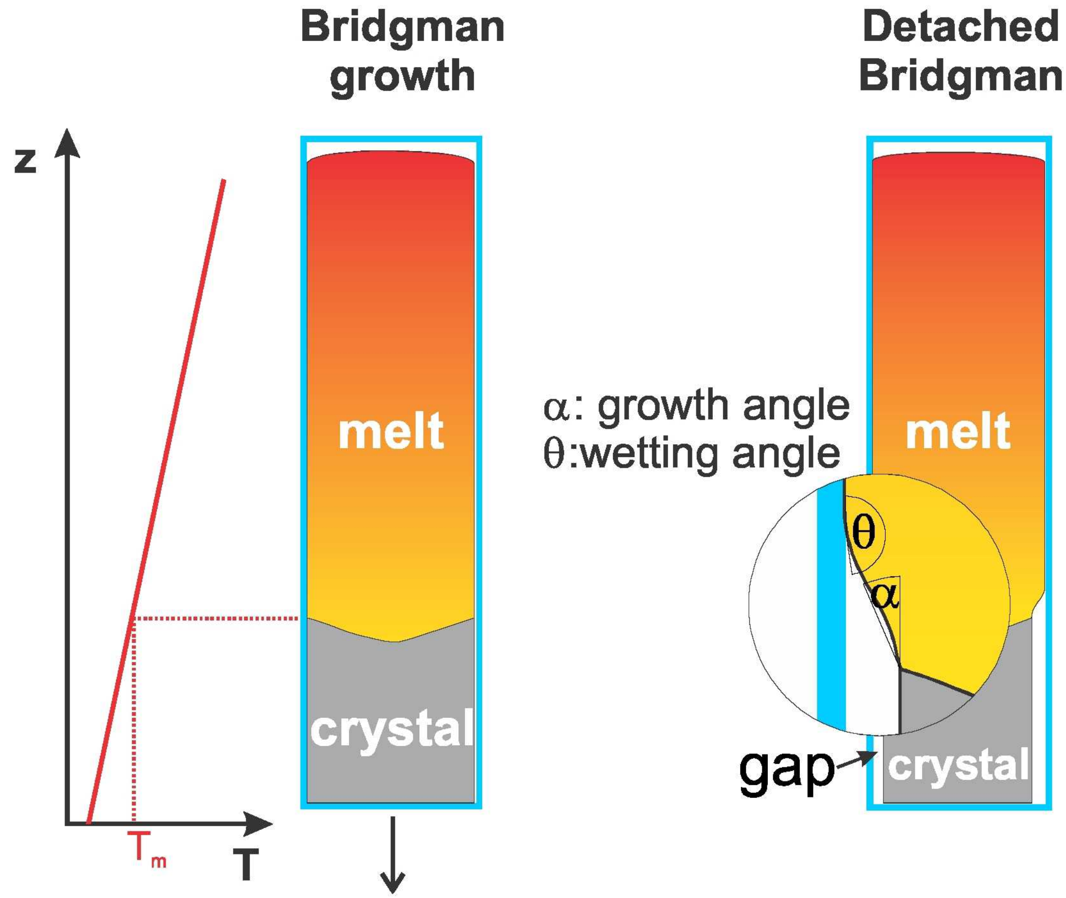
Presentation Outline

- Introduction to detached growth
- Experimental results
- Detached growth theory
- Calculation of meniscus shapes
    - Large Bond numbers > $O(1)$
    - Small Bond numbers ~ $O(10^{-6})$, microgravity case
    - Intermediate Bond numbers
- Conclusions

Principles of Detached Bridgman Growth

Sufficient condition for detachment[1,2]:

$$(\alpha+\theta \geq 180°)$$



Advantages

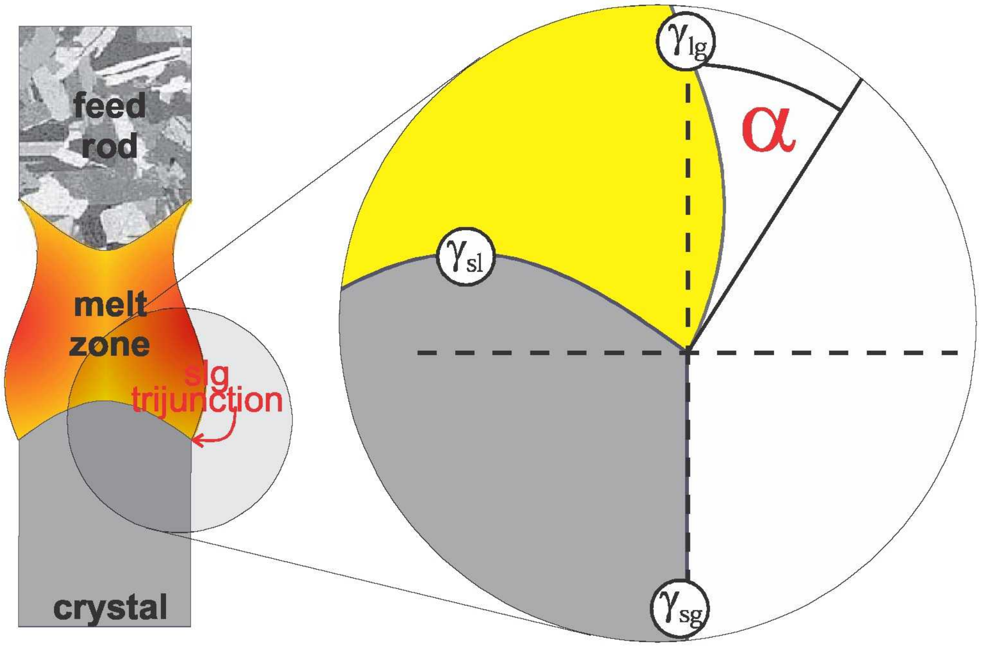
- No sticking of the crystal to the ampoule wall
- Reduced stress
- Reduced dislocations
- No heterogeneous nucleation by the ampoule
- Reduced contamination

[1]V. S. Zemskov: Fiz. Khim. Obrab. Mater. 17 (1983) 56

[2]T.Duffar, I.Paret-Harter, P.Dusserre: J.Crystal Growth 100 (1990) 171.

Growth Angle and Wetting Angle

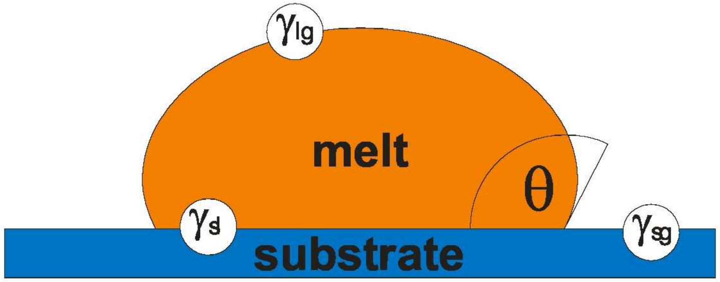
Growth angle α:



$$\alpha = \arccos\left(\frac{\gamma_{sg}^2 + \gamma_{lg}^2 - \gamma_{sl}^2}{2 \cdot \gamma_{sg} \cdot \gamma_{lg}}\right)$$

W.Bardsley, F.C. Frank, G.W. Green, D.T.J. Hurle: J. Crystal Growth 23 (1974), 341

Wetting angle θ:



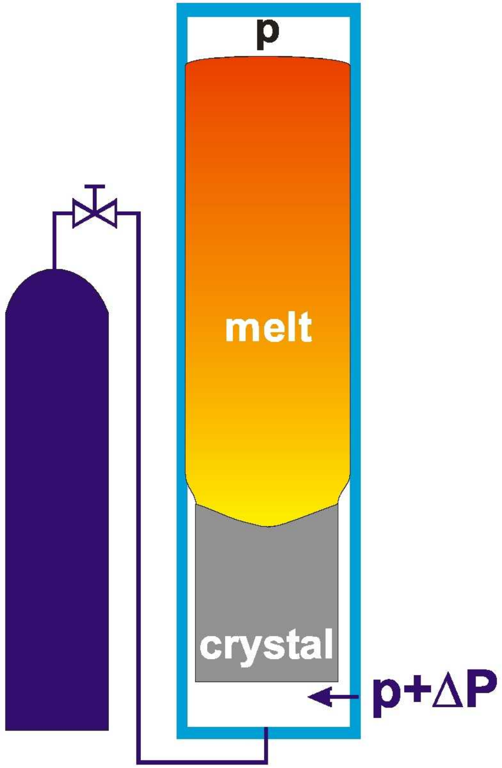
$$\theta = \arccos \frac{\gamma_{sg} - \gamma_{sl}}{\gamma_{lg}}$$

(Young equation)

γ_{lg}: surface energy liquid-gas
γ_{sl}: surface energy solid-liquid
γ_{sg}: surface energy solid-gas

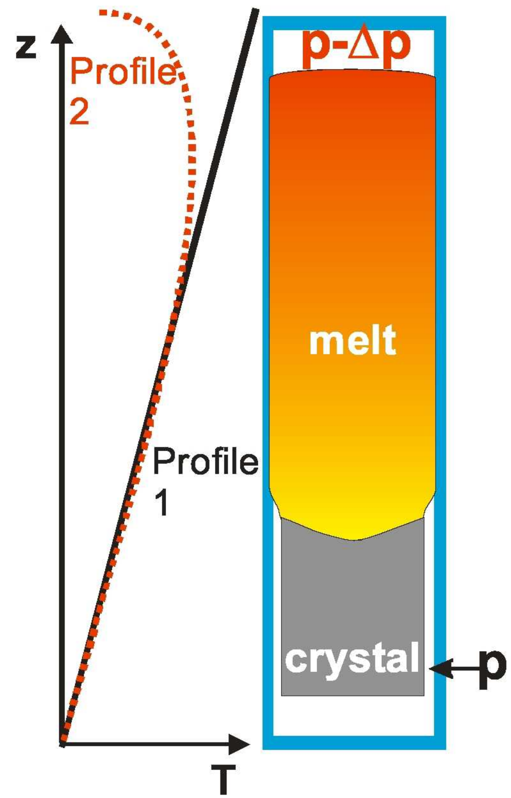
Gas Pressure Below Meniscus

Higher pressure below the meniscus by active pressurization

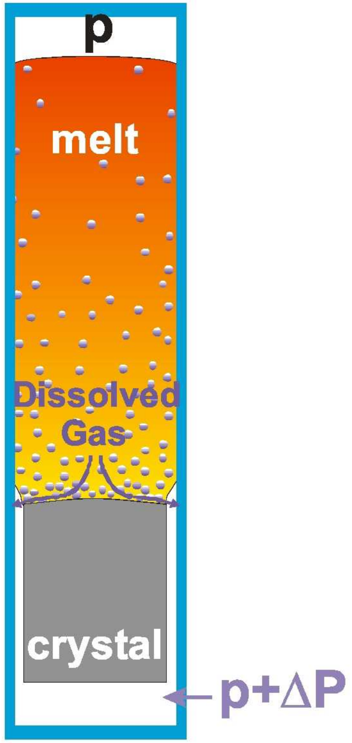


T. Duffar, P. Dusserre, F. Picca, S. Lacroix, N. Giacometti: J. Crystal Growth 311 (2000), 434

Higher pressure below the meniscus by temperature reduction above the melt



Higher pressure below the meniscus due to segregation at the interface



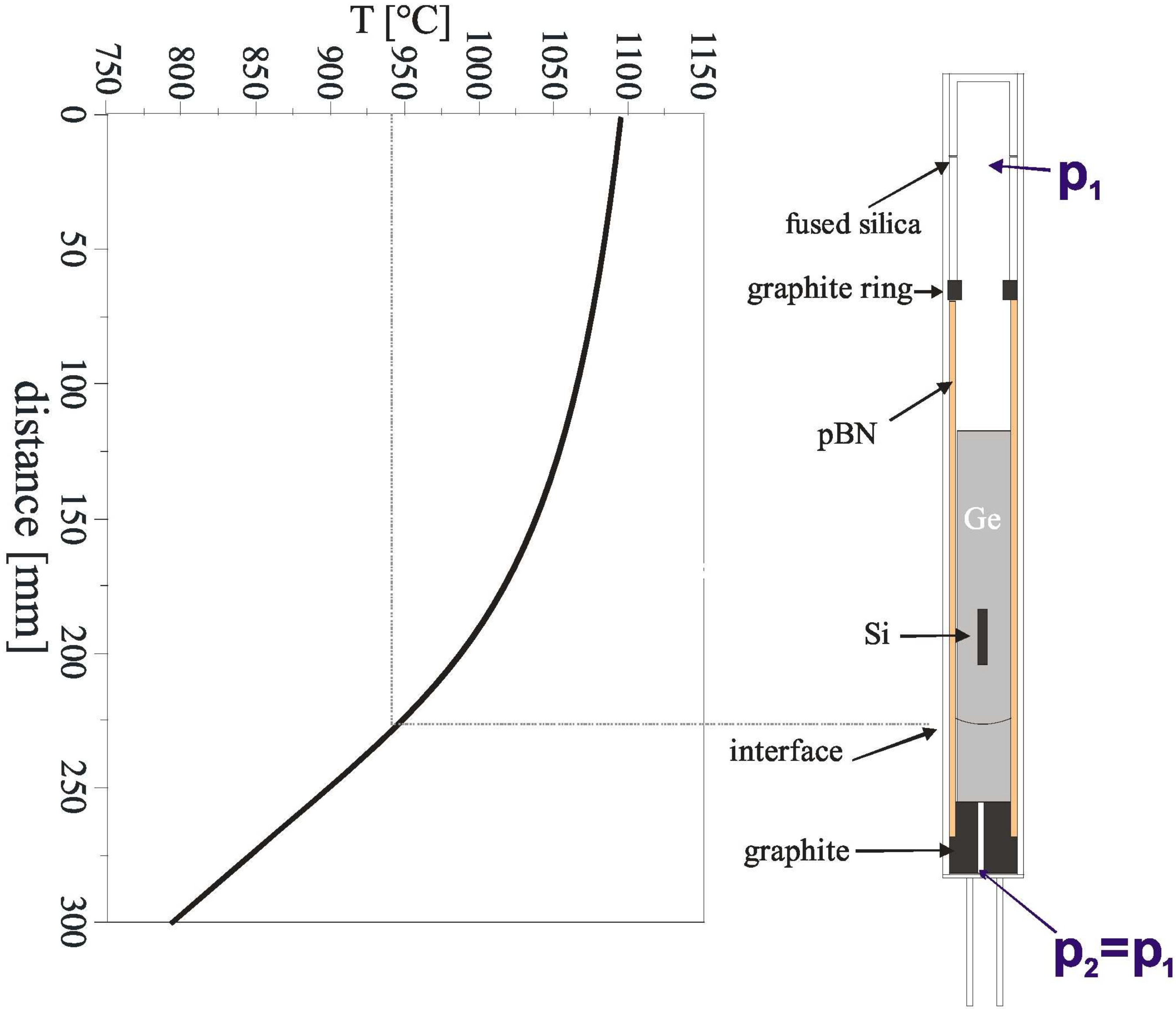
W.R. Wilcox, L. Regel: Microgravity Sci.Technol. VIII (1995), 56

Detached Growth without Pressure Difference

The gas volumes above the melt and below the meniscus are connected

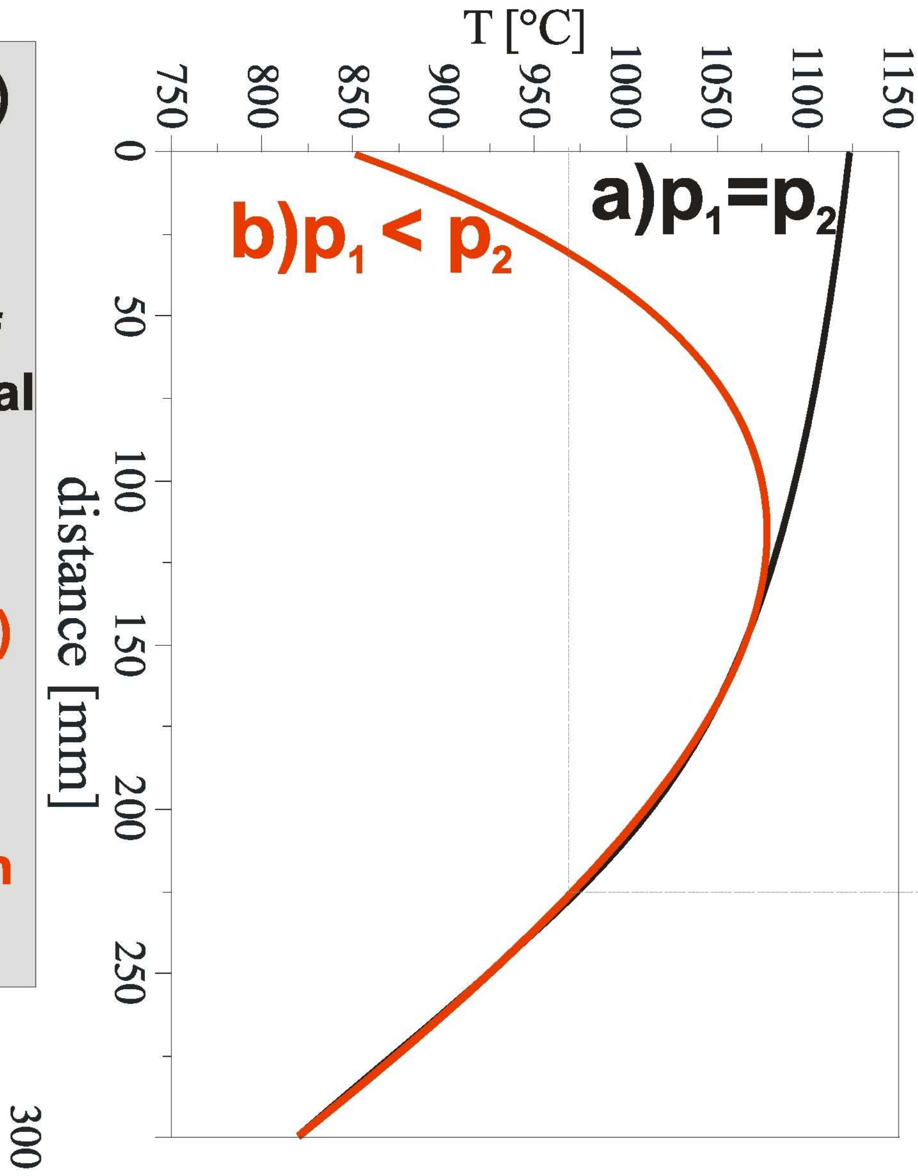
$\Rightarrow$ $p_2 = p_1$

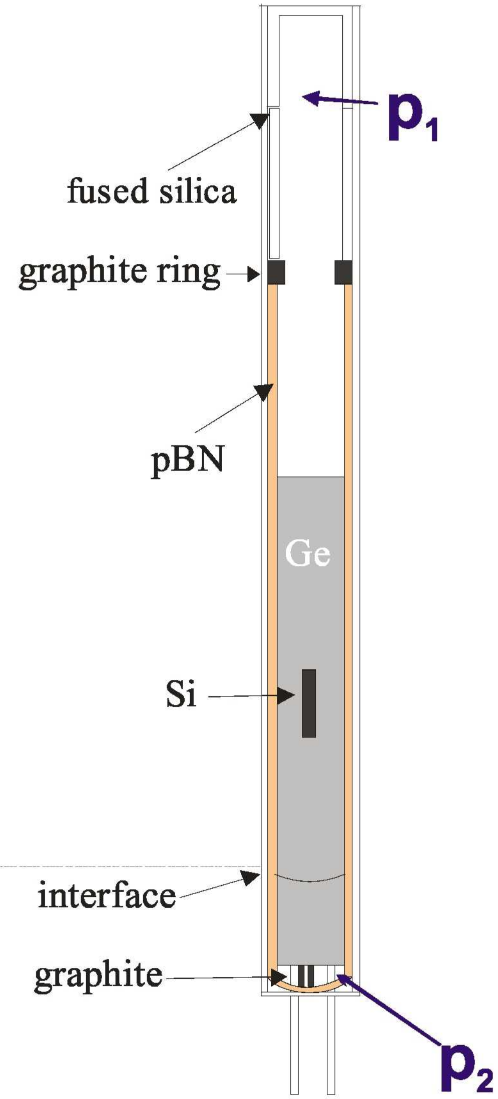
no pressure difference possible



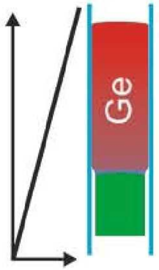
Growth with Forced Pressure Difference

T-Profile a)
(p_1=p_2)
↓
Melting of feed material
(p_1=p_2)
↓
T-Profile b)
(p_1<p_2)
↓
Translation
(p_1<p_2)

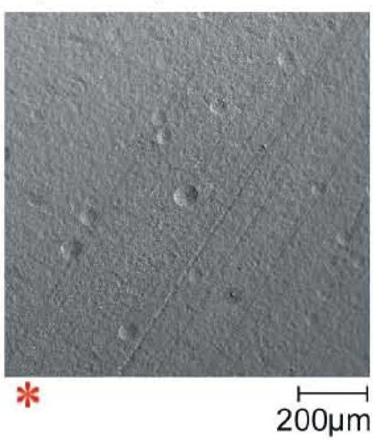


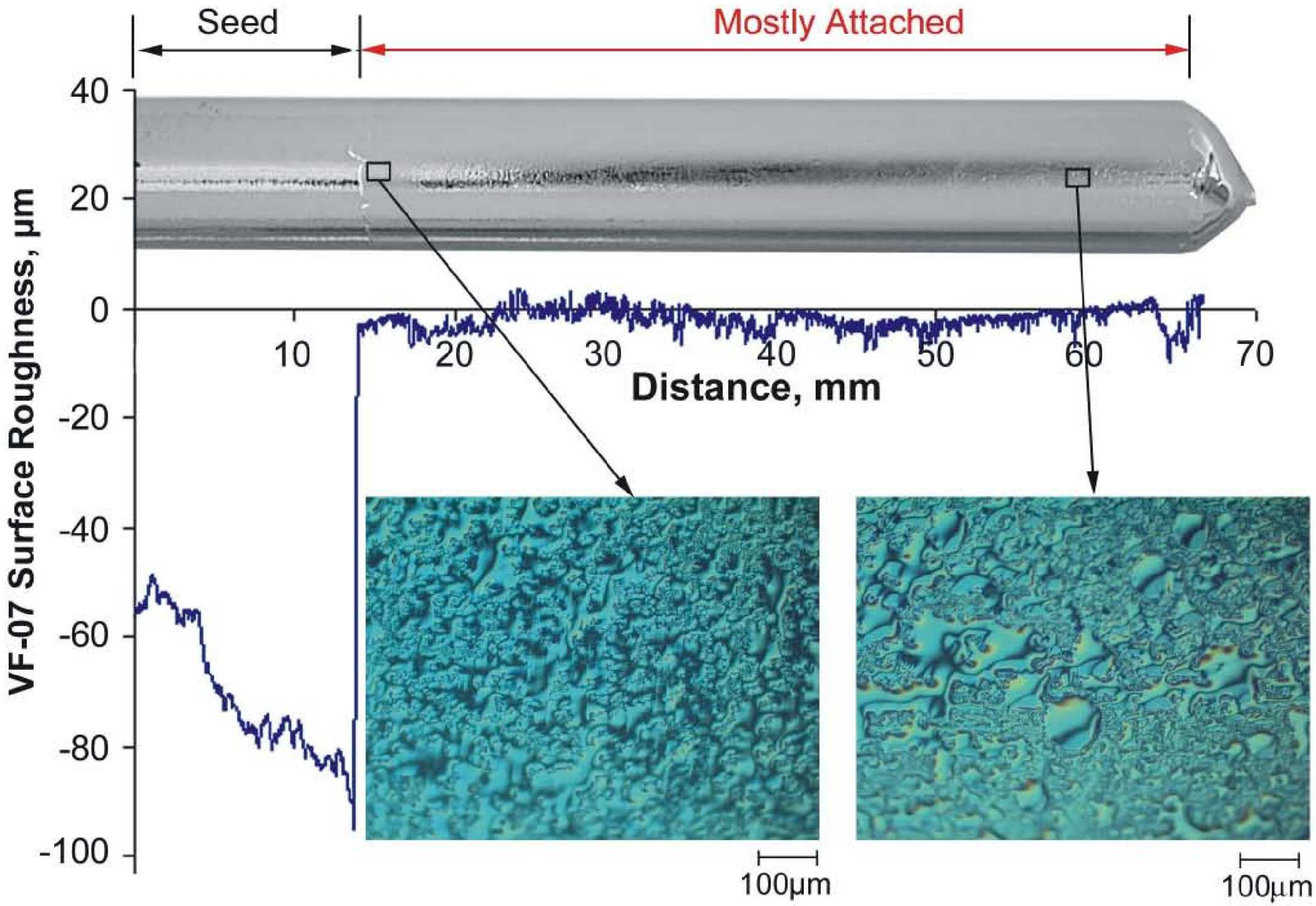


Effect of Open Bottom pBN Ampoule (Ge)



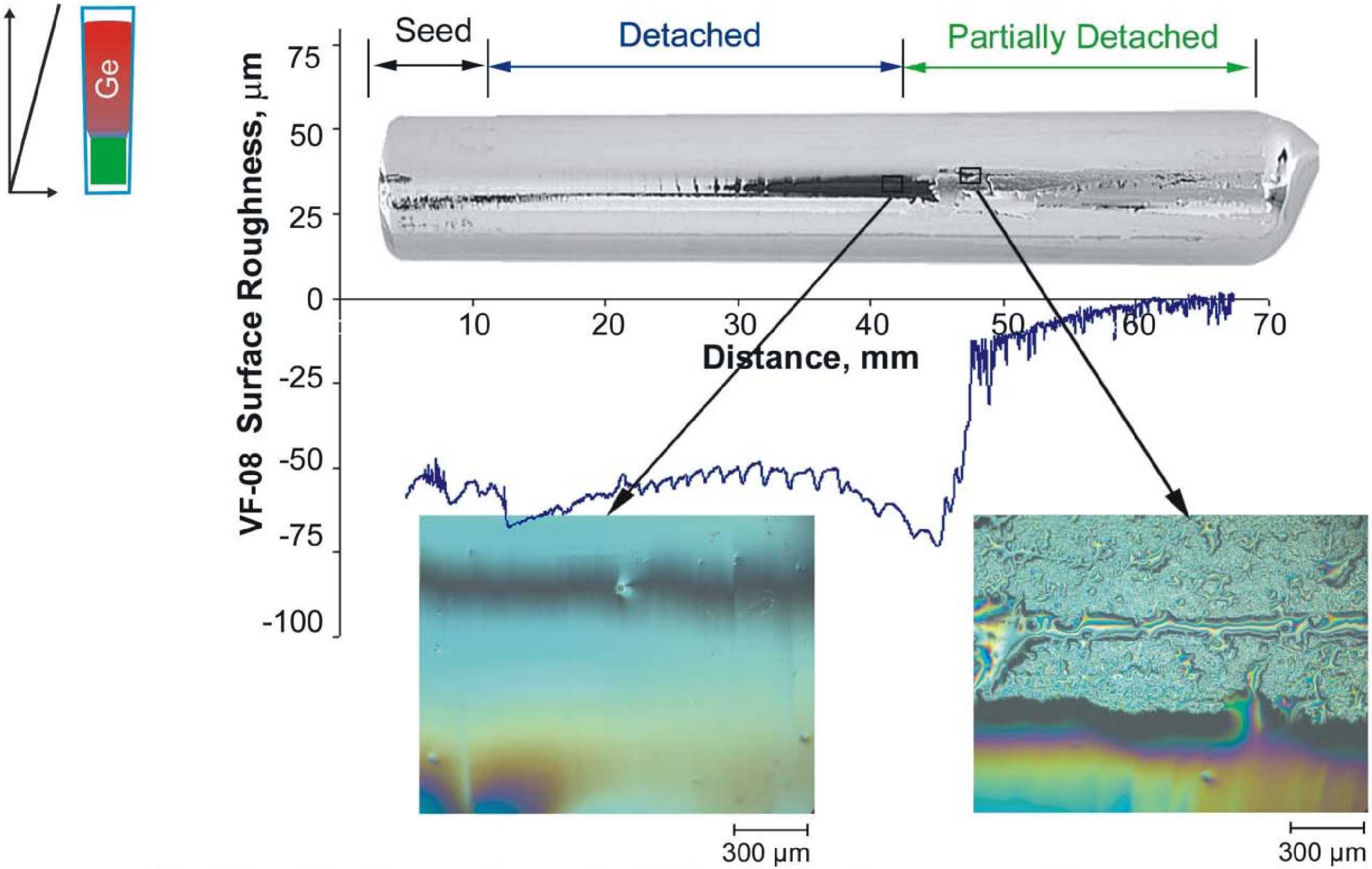
pBN Ampoule Surface





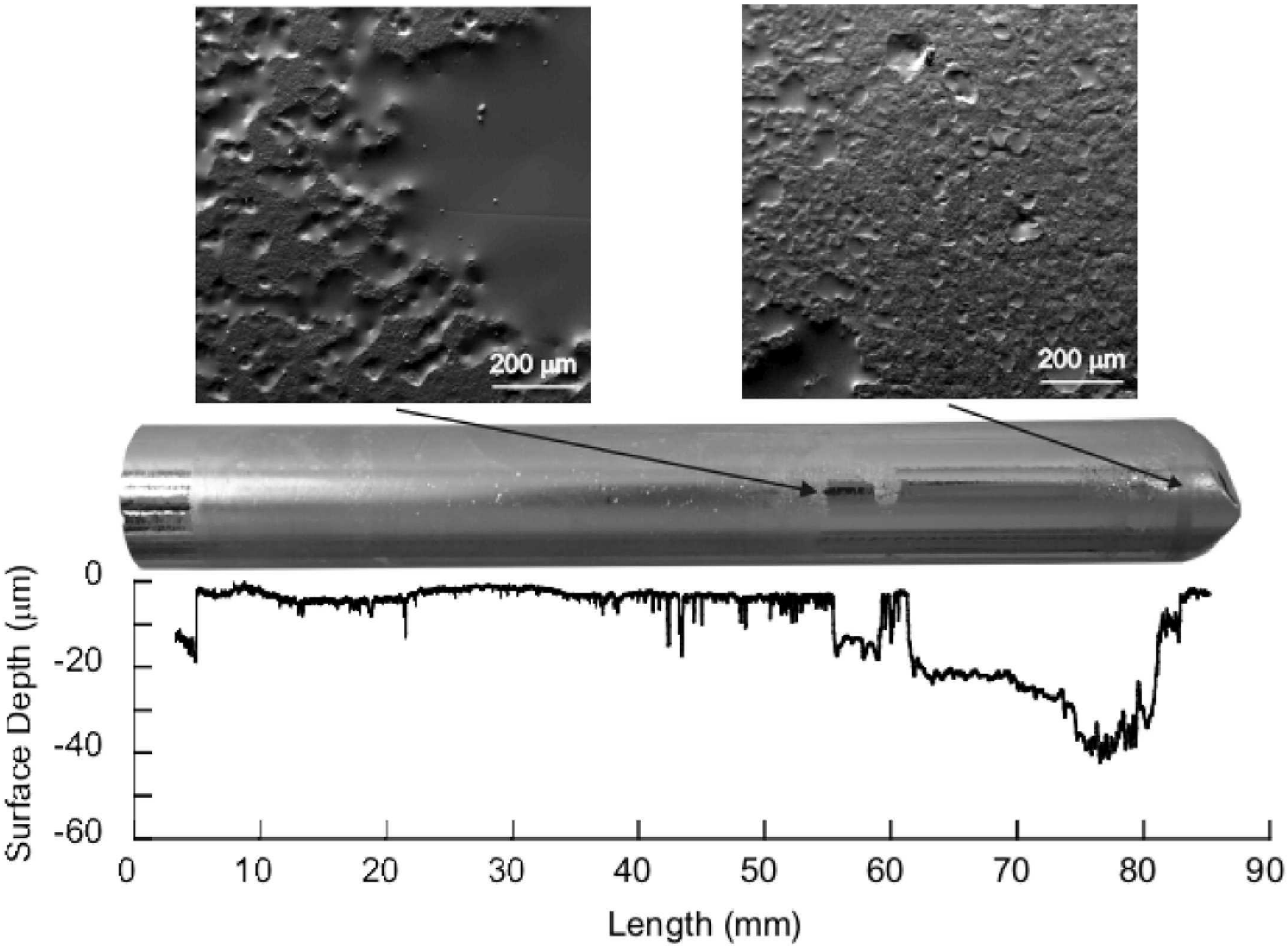
- **For Ge in an open pBN ampoule, a pressure difference sufficient for detachment cannot develop.**

Effect of Closed Bottom pBN Ampoule (Ge)



➢ **For Ge in a closed pBN ampoule, enough pressure develops in the gap to produce detachment.**

Effect of Open Bottom pBN Ampoule (GeSi)



M. P. Volz, M. Schweizer, N. Kaiser, S. D. Cobb, L. Vujisic, S. Motakef, F. R. Szofran, JCG 237-239 (2002) 1844-1848

In-situ Pressure Control Setup

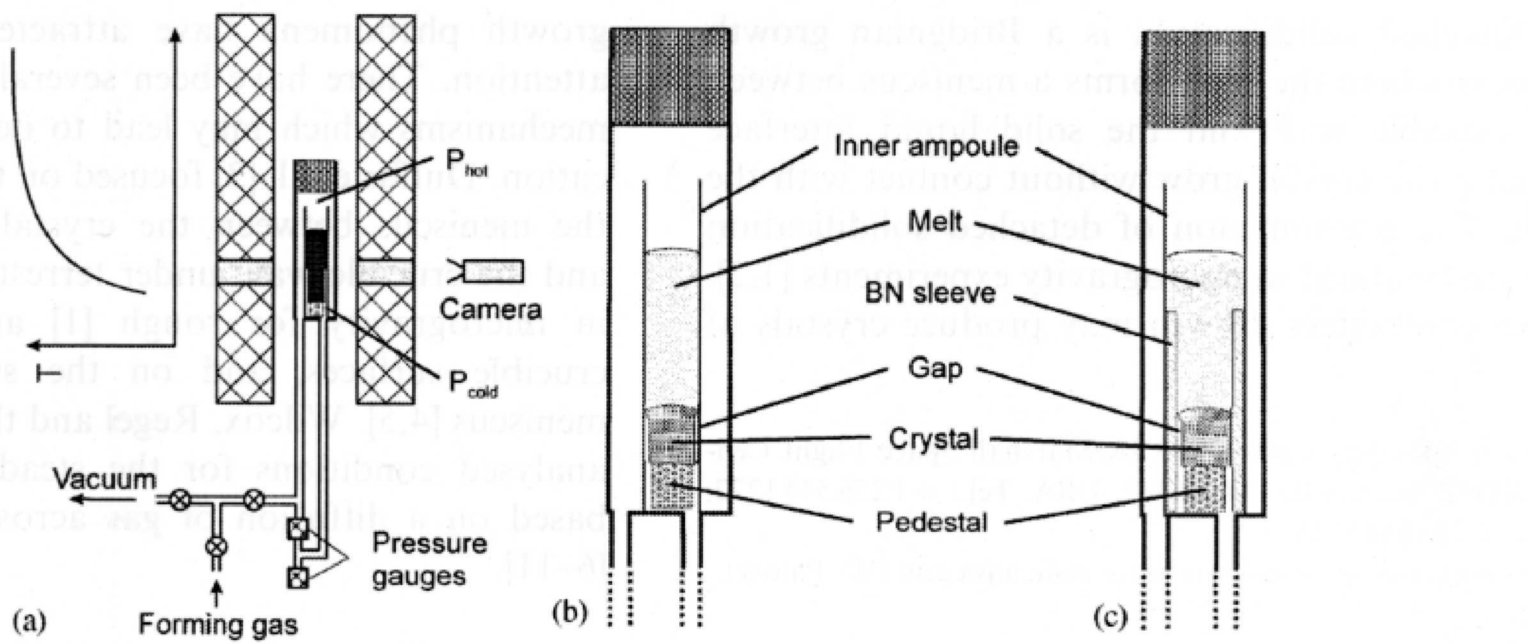
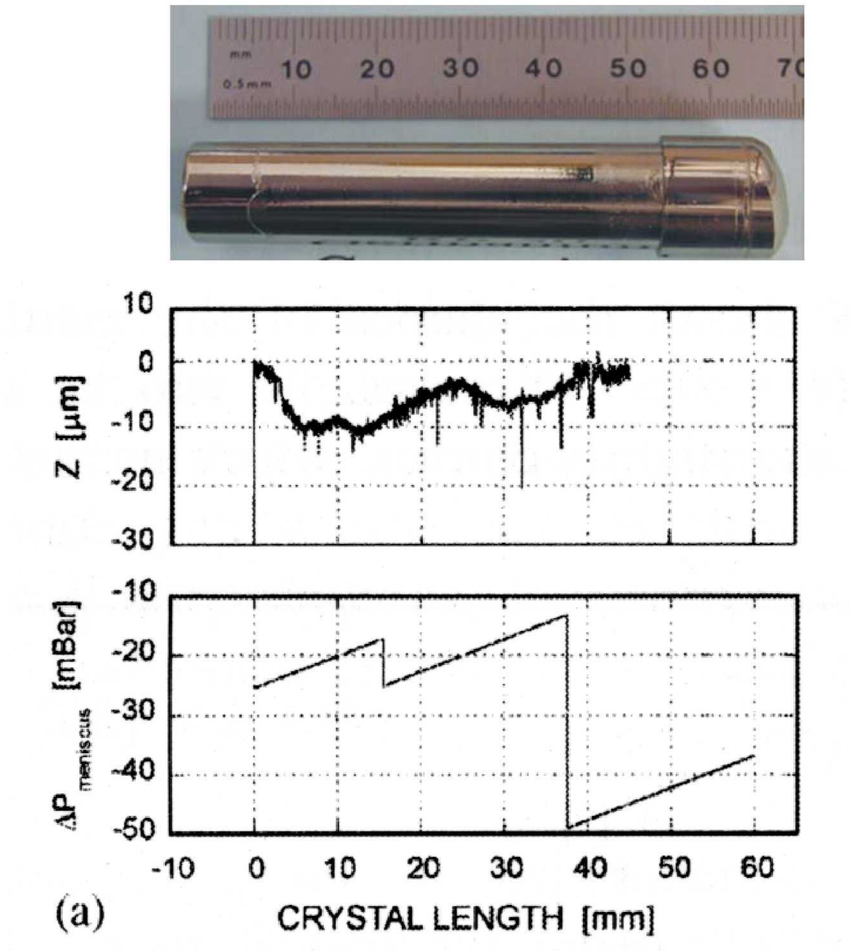
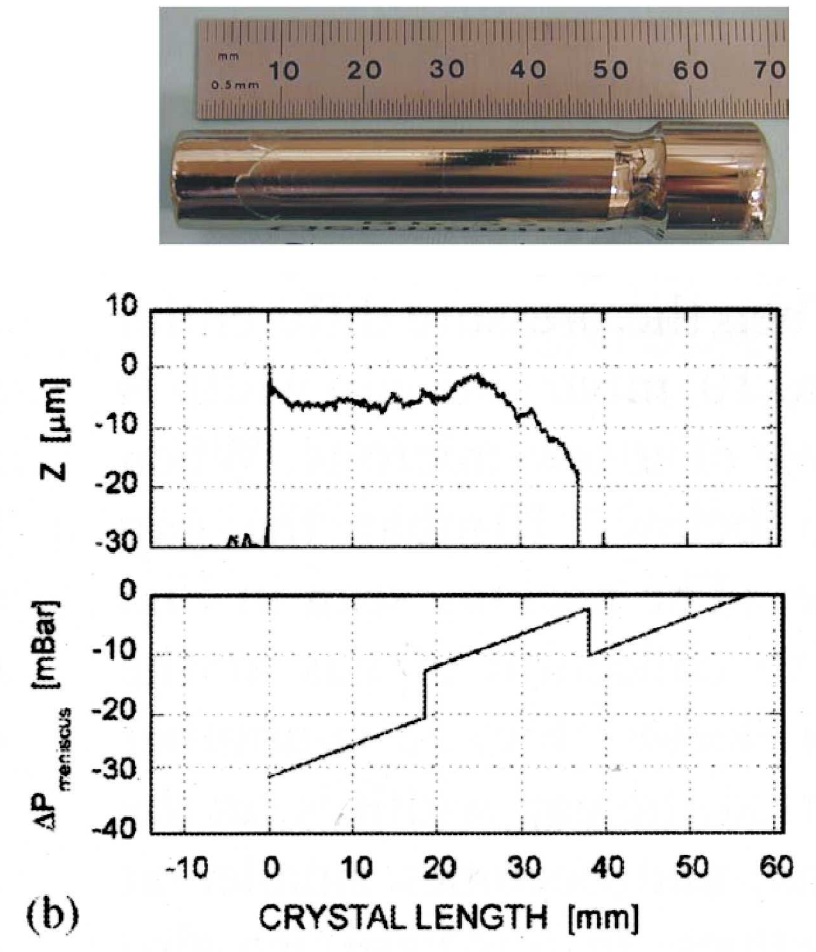


Fig. 1. Experimental system: (a) growth configuration; (b) ampoule with silica crucible; (c) ampoule with pBN insert.

W. Palosz, M. P. Volz, S. Cobb, S. Motakef, F. R. Szofran, JCG 277 (2005) 124-132

Ge Grown in pBN ampoules





W. Palosz, M. P. Volz, S. Cobb, S. Motakef, F. R. Szofran, JCG 277 (2005) 124-132

Etch Pit Densities in Detached/Attached Crystals

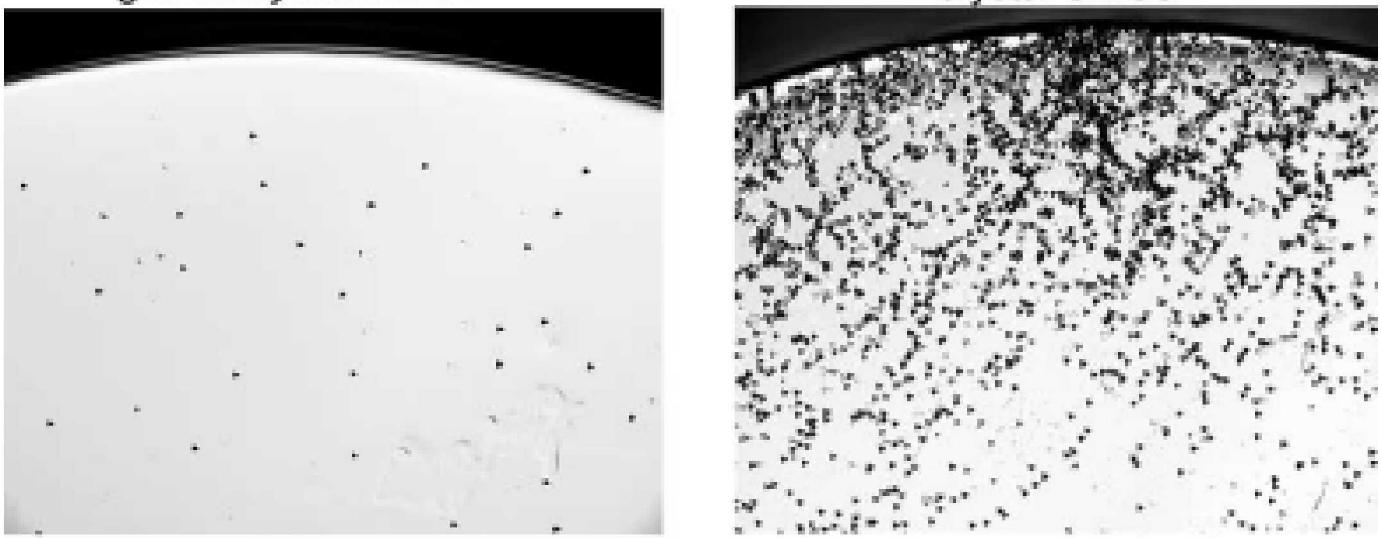


Fig. 5. Micrograph from the detached-grown sample UMC7 and from the attached-grown sample UMC6.

M. Schweizer, S. D. Cobb, M. P. Volz, J. Szoke, F. R. Szofran, JCG 235 (2002) 161-166

Etch Pit Density Variation With Attachment

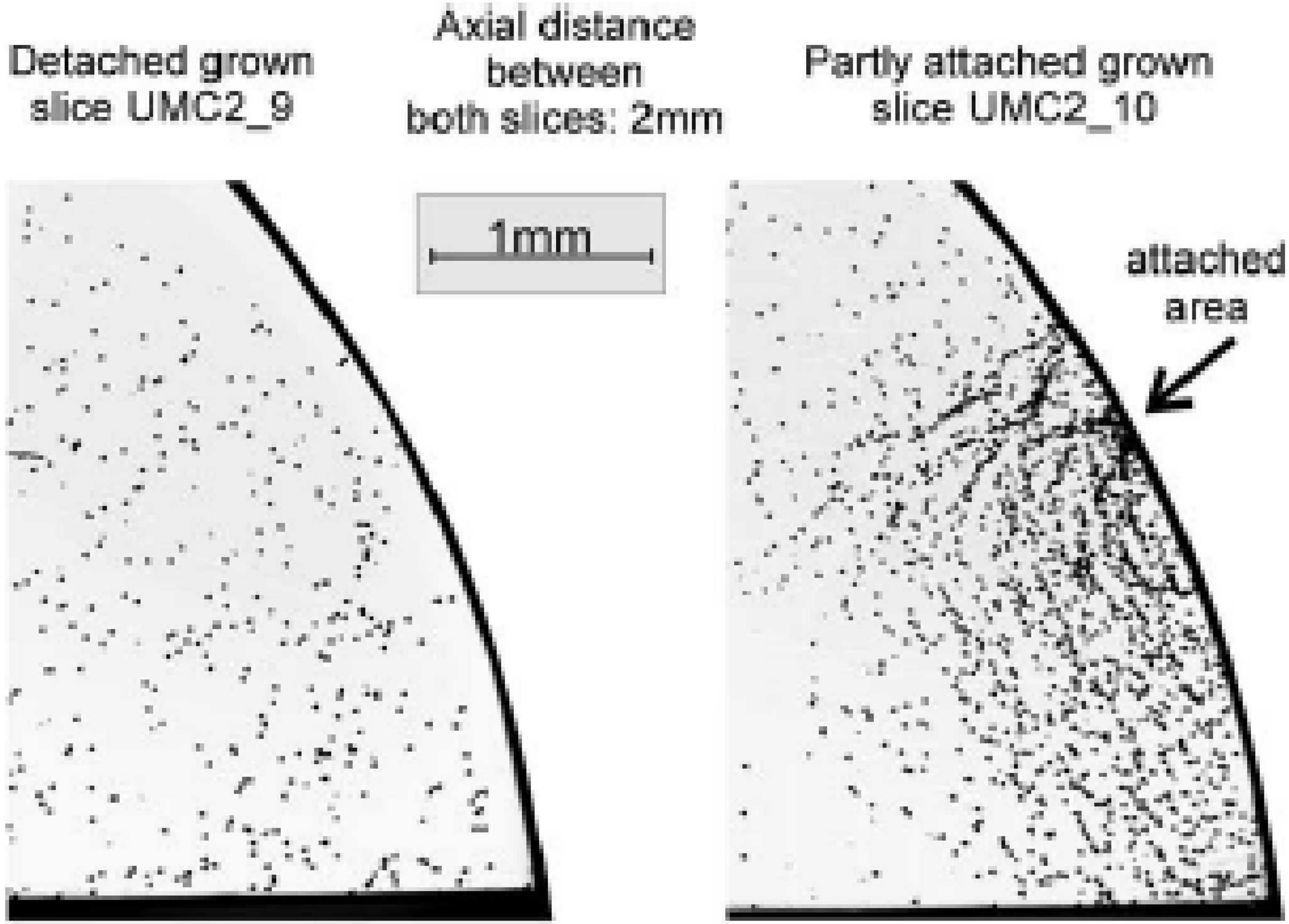
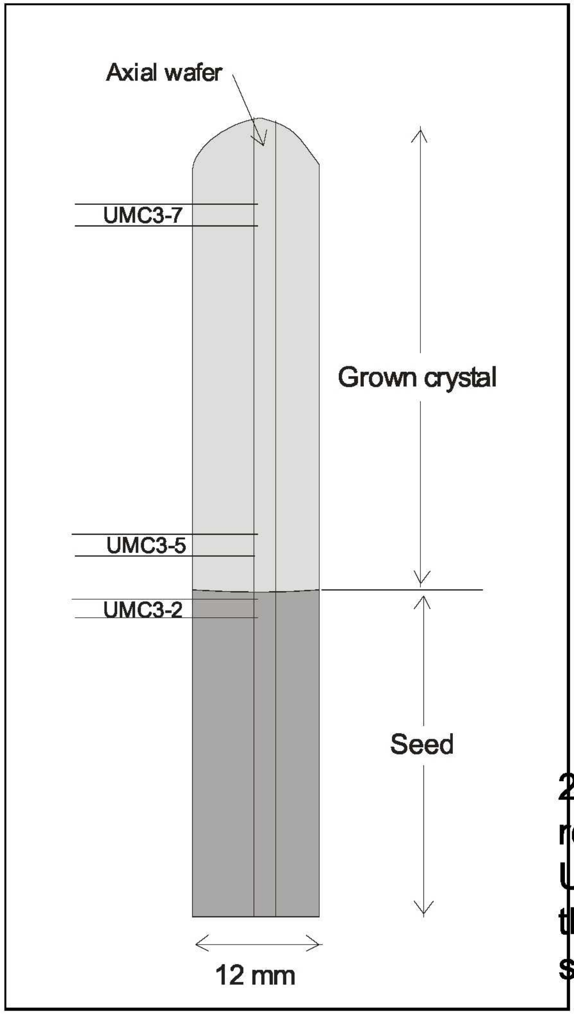


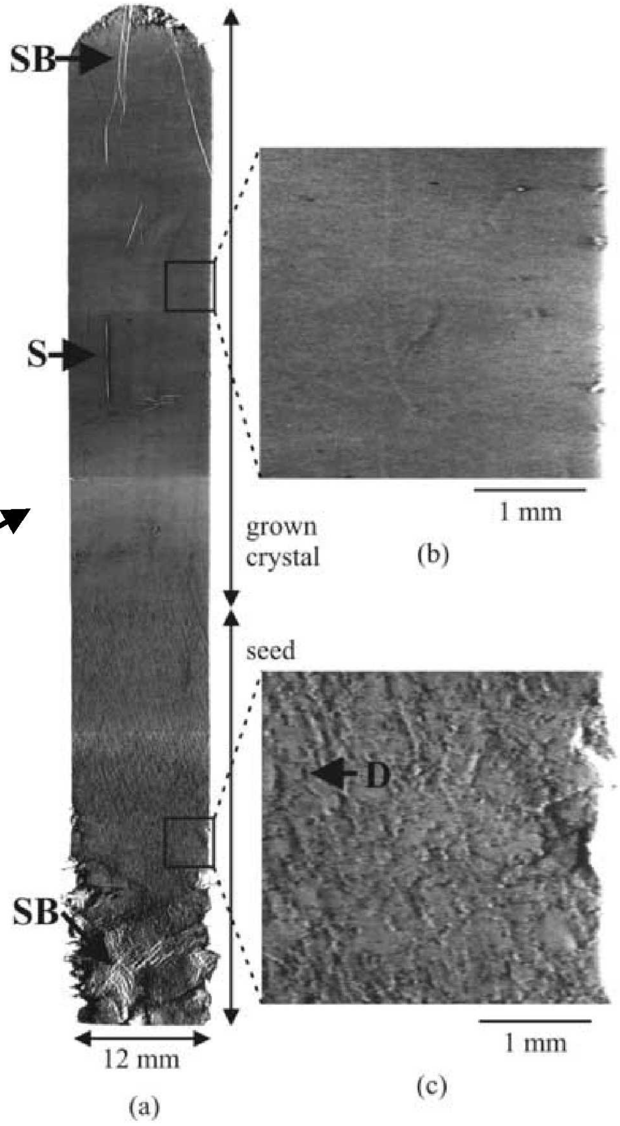
Fig. 6. Localized increased EPD after the crystal attaches partially to the wall.

M. Schweizer, S. D. Cobb, M. P. Volz, J. Szoke, F. R. Szofran, JCG 235 (2002) 161-166

X-Ray Synchrotron Topography of Detached Ge



220 reflection topograph (l = 0.69 Å) recorded from a detached-grown UMC3 crystal wafer cut parallel to the growth axis (S – scratch, SB – subgrain boundary, D – dislocation).



M. P. Volz, M. Schweizer, B. Raghothamachar, M. Dudley, J. Szoke, S. D. Cobb, F. R. Szofran, JCG 290 (2006) 446-451

Schematic Diagram of Detached Solidification

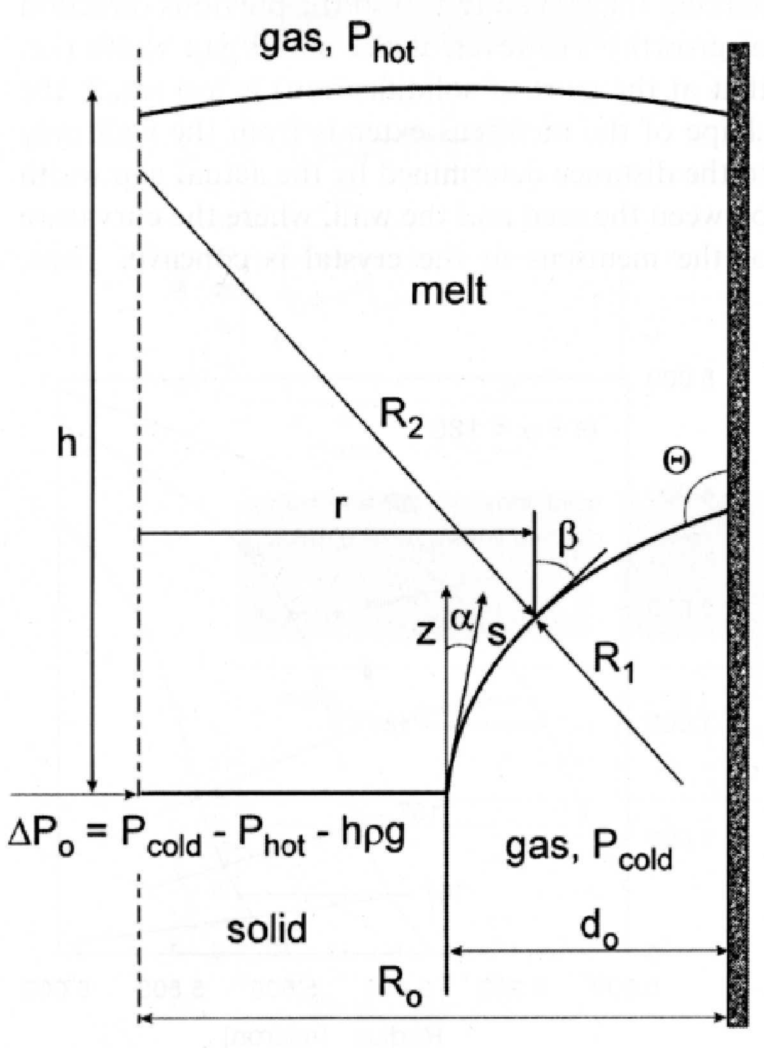


Fig. 2. Schematic diagram of detached solidification.

W. Palosz, M. P. Volz, S. Cobb, S. Motakef, F. R. Szofran, JCG 277 (2005) 124-132

Mathematical Formulation

$$\frac{\dfrac{d^2z}{dr^2}}{\left(1+\left(\dfrac{dz}{dr}\right)^2\right)^{3/2}}+\frac{\dfrac{dz}{dr}}{r\left(1+\left(\dfrac{dz}{dr}\right)^2\right)^{1/2}}=\Delta P - Bz(r)$$

Young-Laplace Equation

$$\Delta P=\frac{\Delta P_m r_0}{\gamma},\qquad \Delta P_m = P_{top} - P_{bottom} + \rho g H$$

ΔP : Dimensionless pressure differential across the meniscus

$$B=\frac{\rho g_0 r_0^2}{\gamma}$$

B = 3.248; Ge, r_0 = 6 mm
B = 4.651; InSb, r_0 = 5.5 mm

B : Bond number; ratio of gravity force to surface tension force

$$\frac{\partial r}{\partial s}=\cos\beta,\qquad \frac{\partial z}{\partial s}=\sin\beta,\qquad \frac{\partial\beta}{\partial s}=-\frac{\sin\beta}{r}+\Delta P - Bz$$

Set of 3 coupled differential equations

Boundary Conditions

$z(0) = 0$; $\beta(0) = 90° - \alpha$;

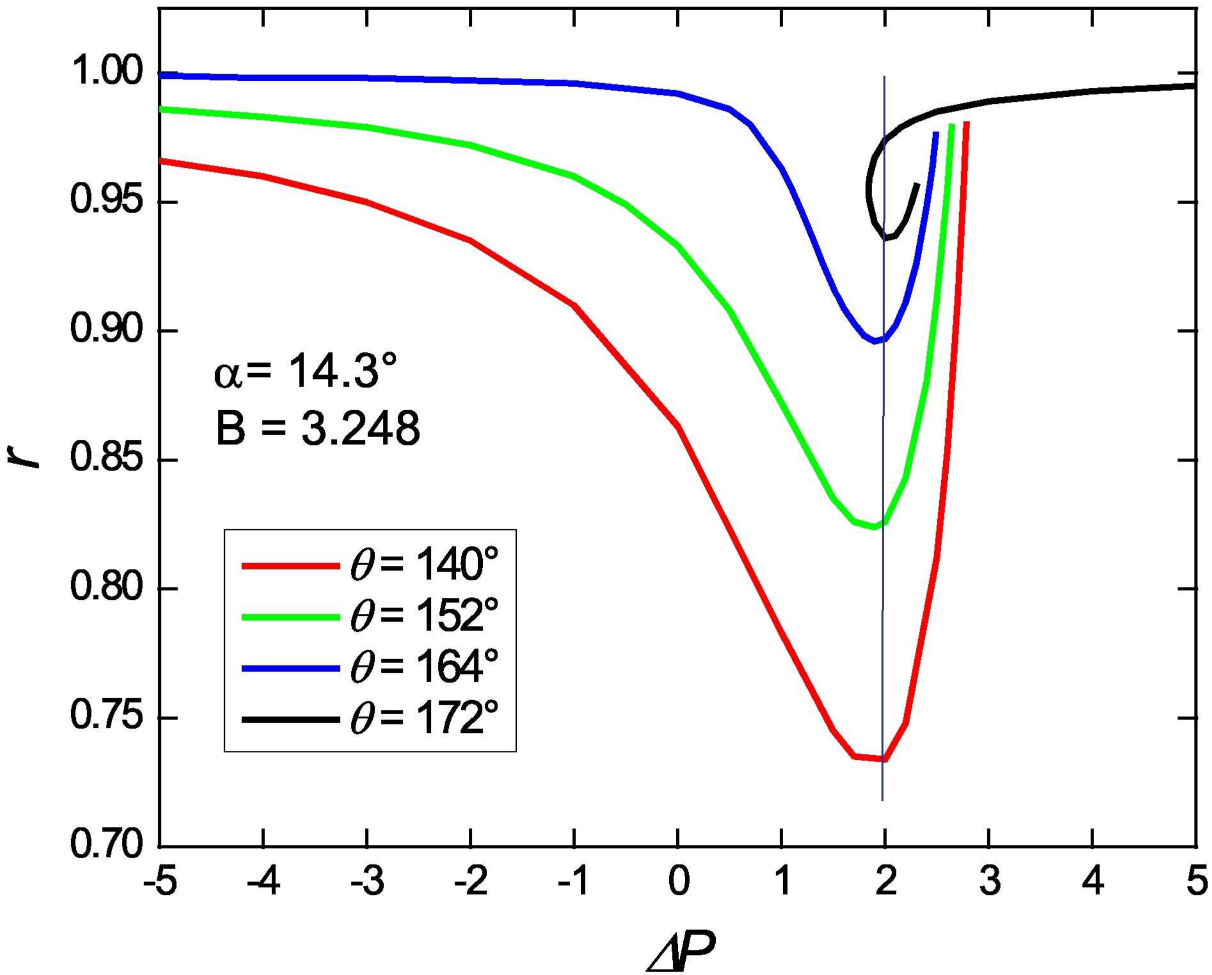
$\beta(1) = \theta - 90°$; $r(1) = 1$

α: growth angle
θ: contact or wetting angle

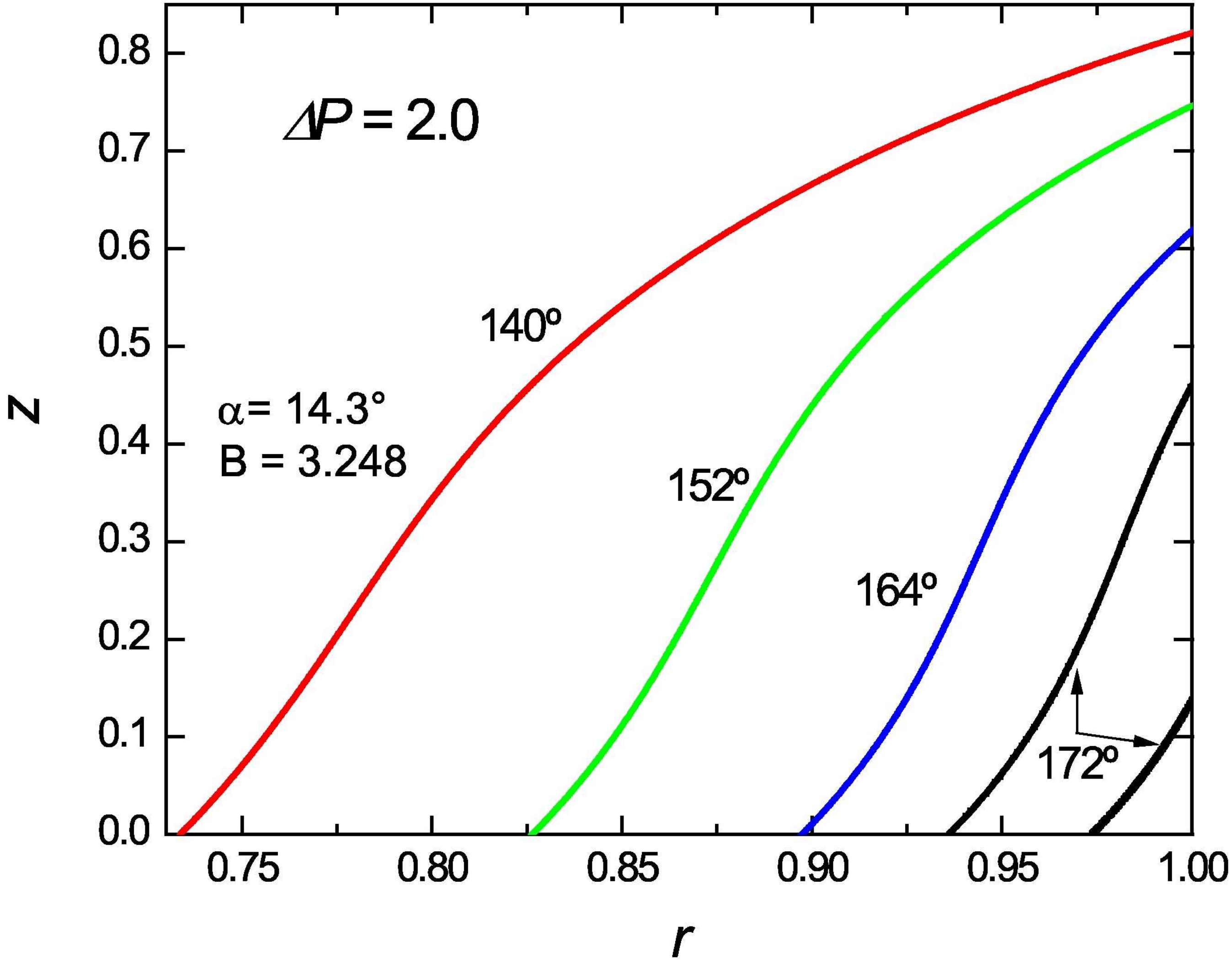
Gap Width vs. Pressure Differential

$\theta+\alpha < 180°$

$\theta+\alpha > 180°$

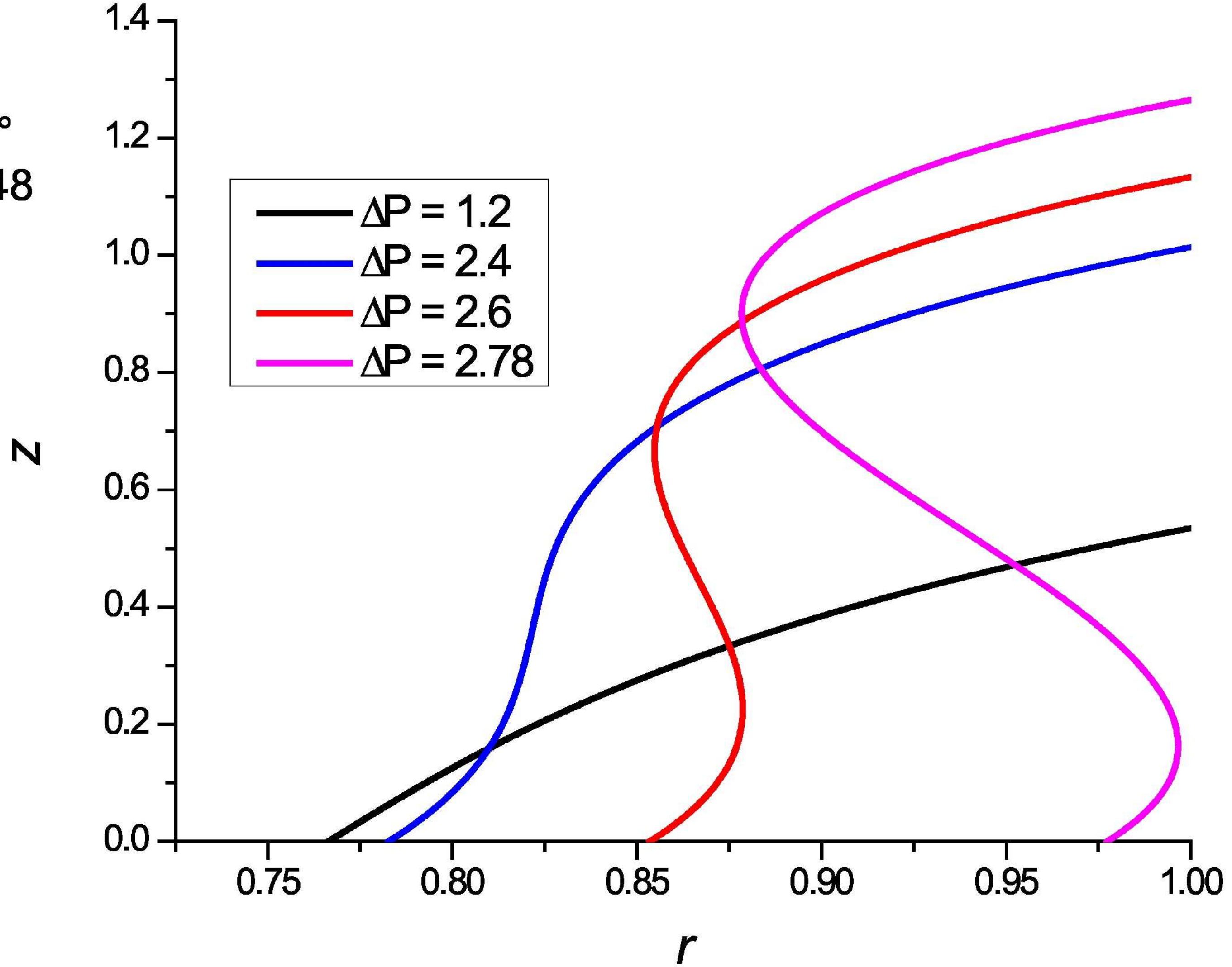


Meniscus Shapes for several Contact Angles

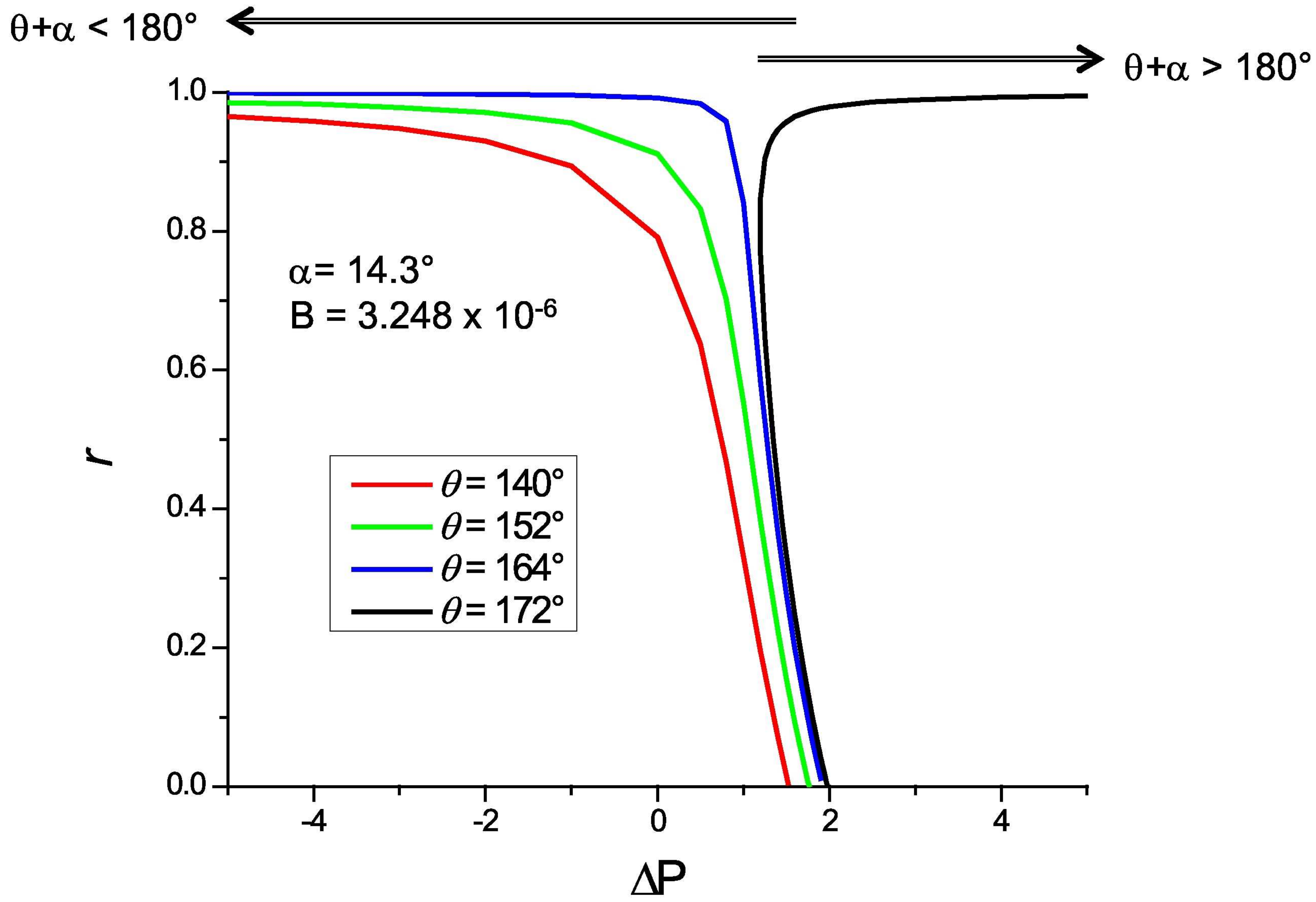


Meniscus Shapes vs. ΔP for $\theta = 140°$

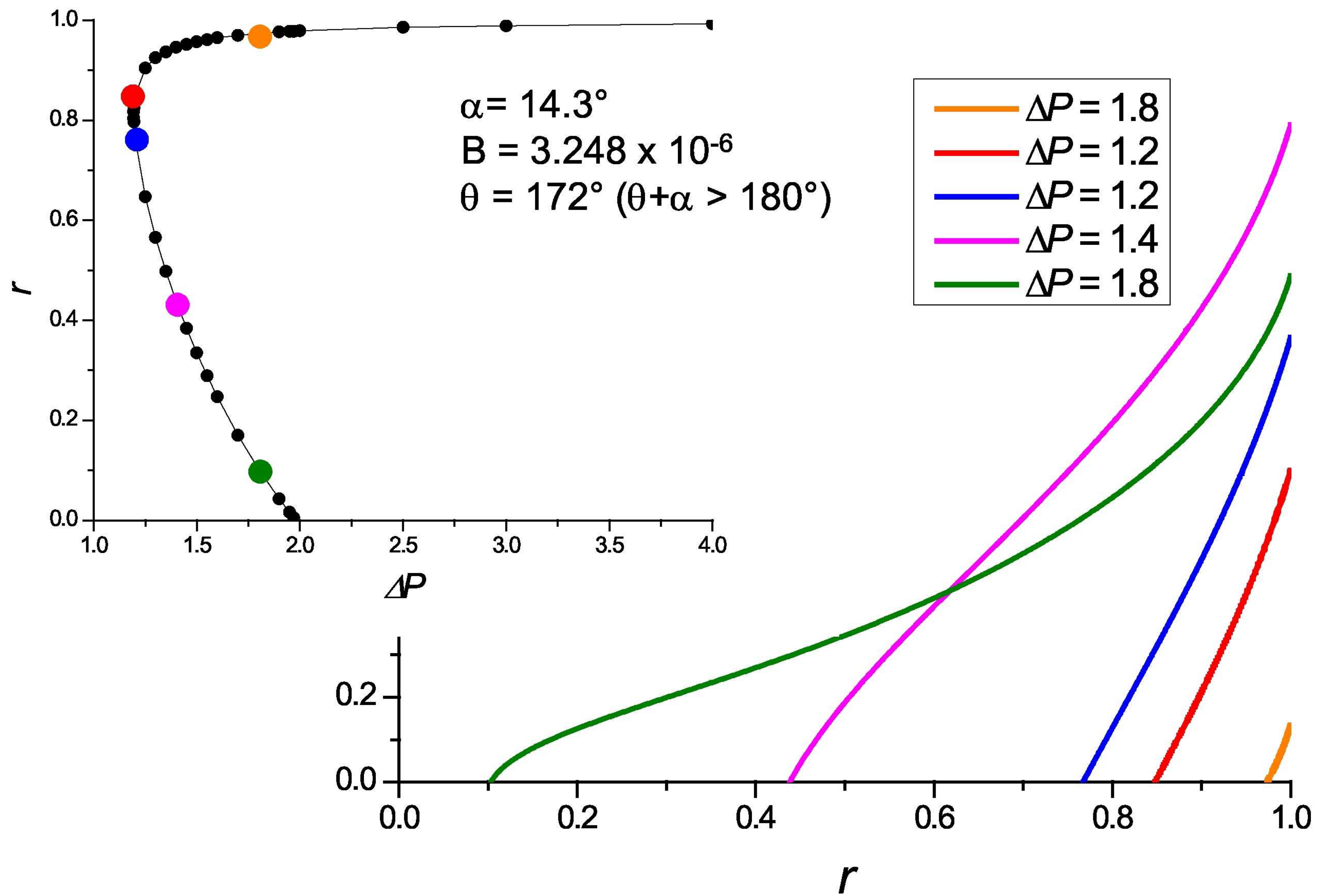
$\alpha = 14.3°$
$B = 3.248$



Gap Width vs. Pressure Differential ($g = 1 \times 10^{-6}\ g_0$)

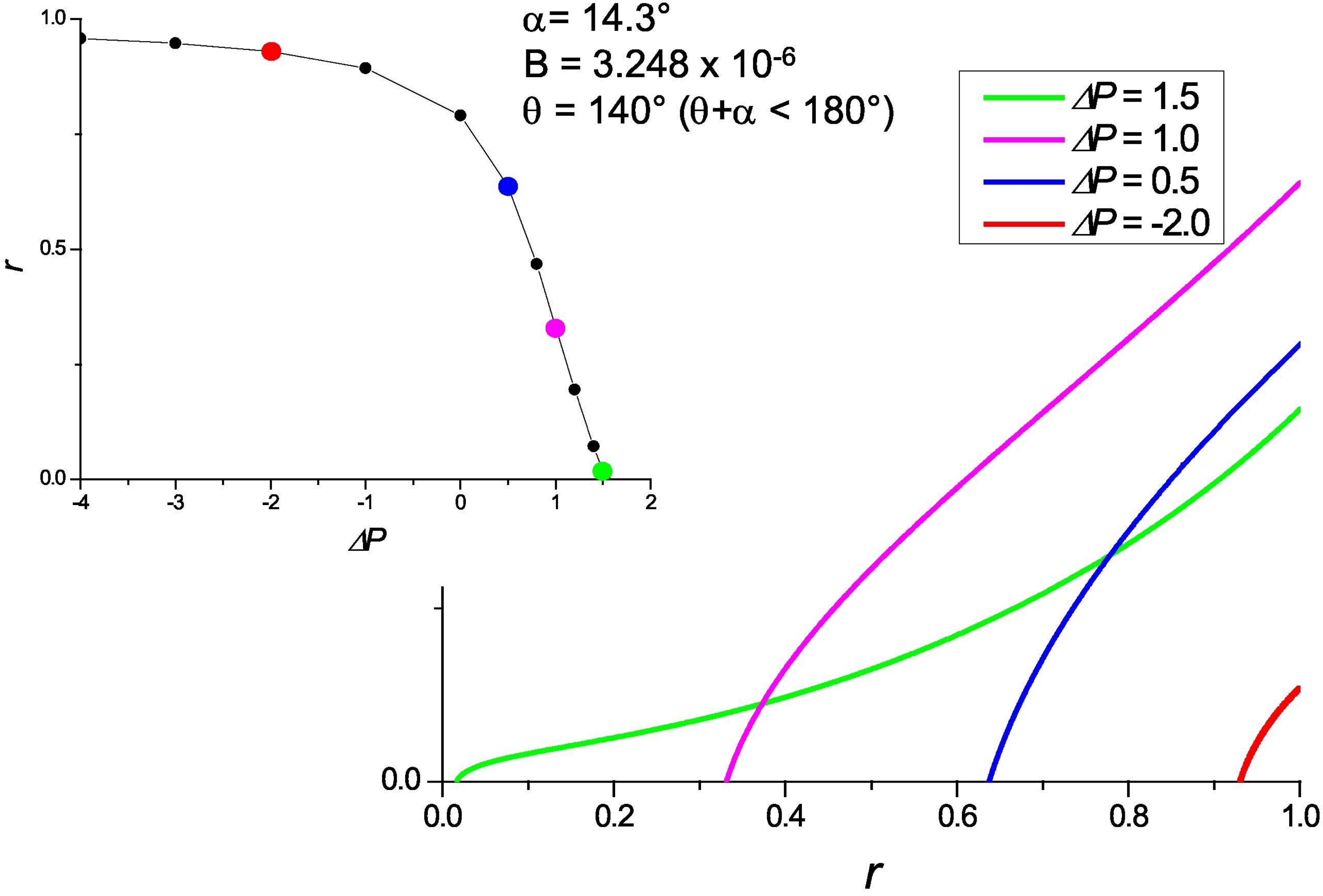


Evolution of Meniscus Shapes (θ = 172°; g = 1 x 10^{-6} g_0)

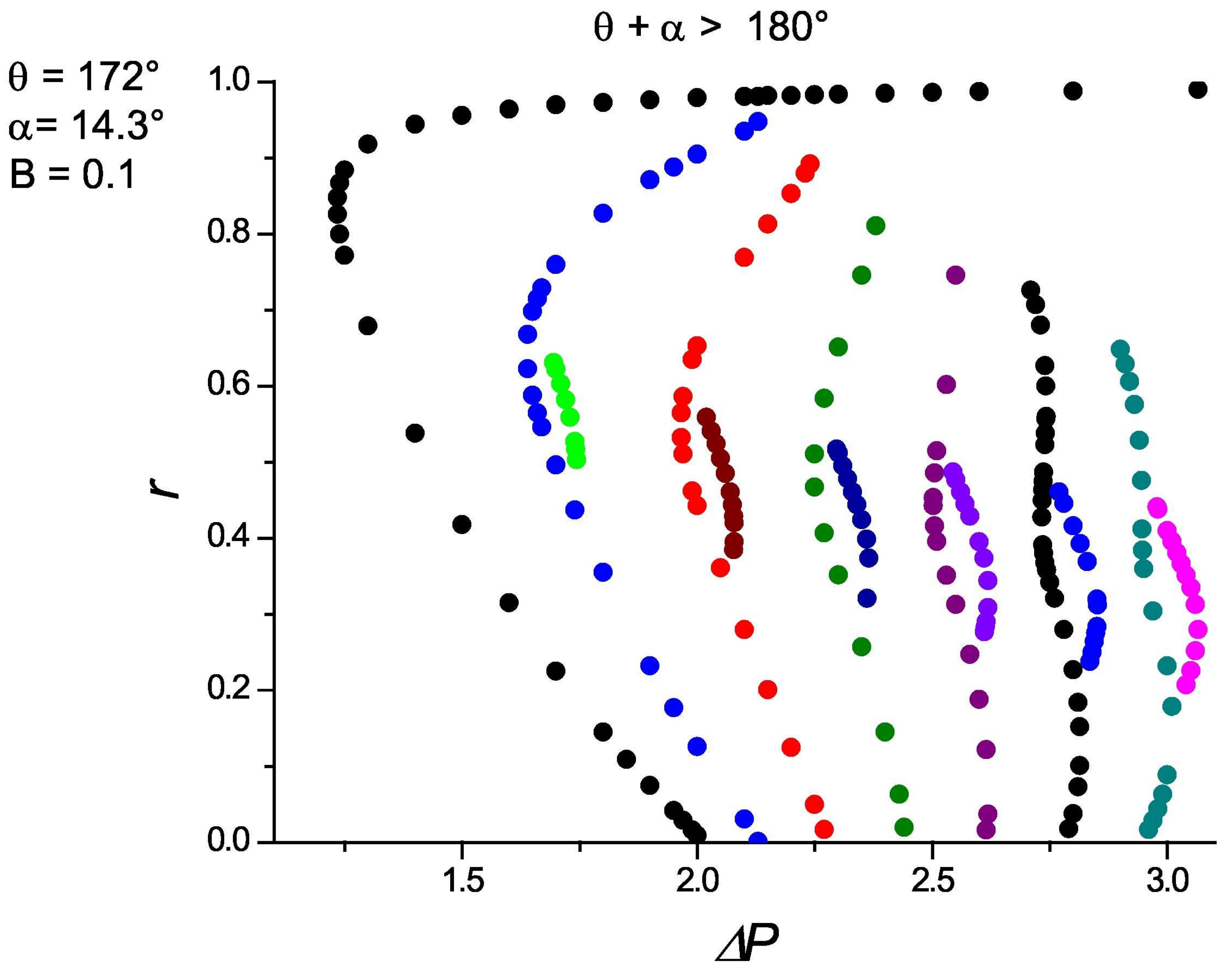


Evolution of Meniscus Shapes (θ = 140°; g = 1 x 10^{-6} g_0)

α= 14.3°
B = 3.248 x 10^{-6}
θ = 140° ($\theta+\alpha$ < 180°)

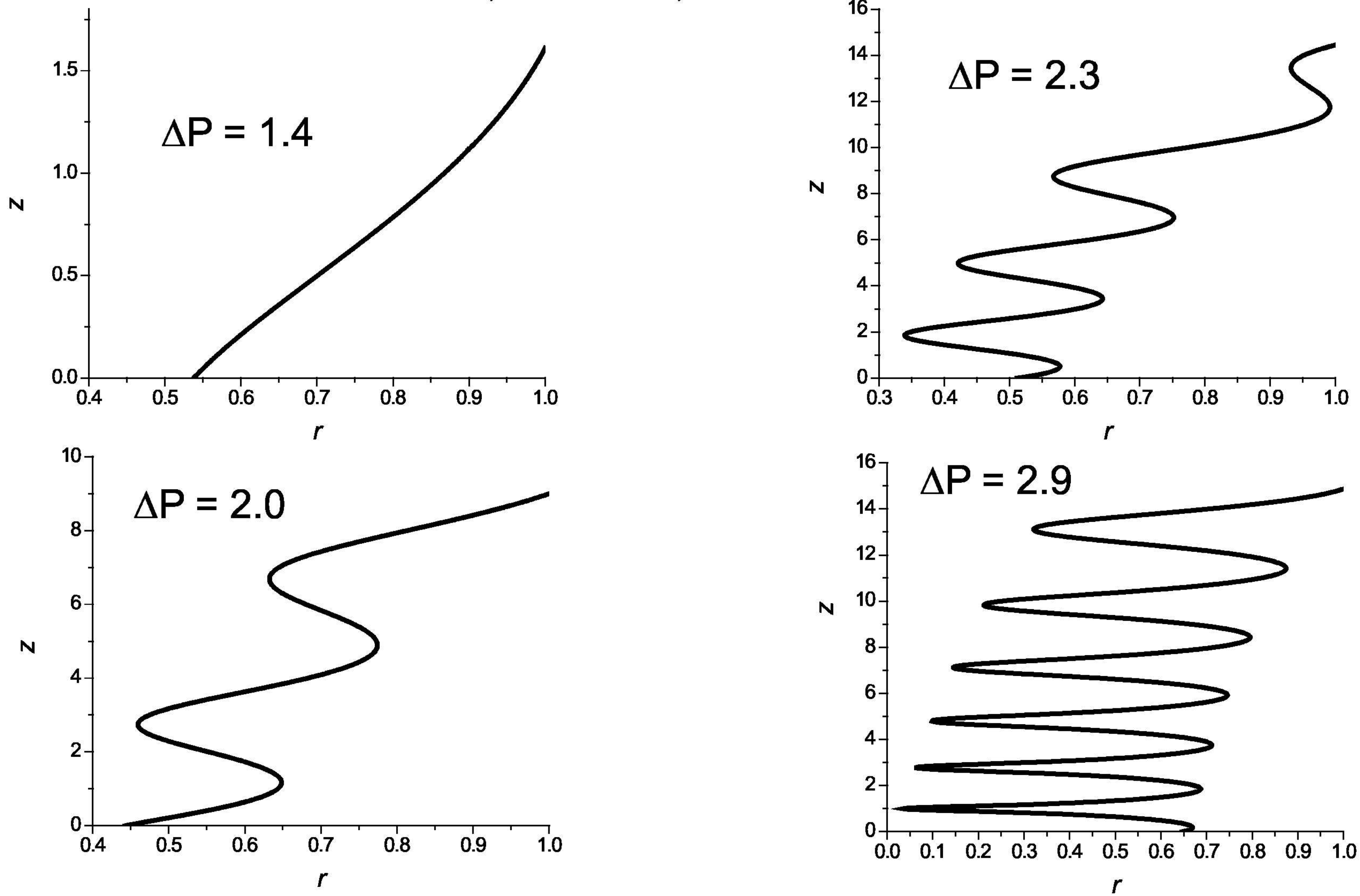


Gap Width vs. ΔP (Intermediate Bond Number)



Meniscus Shapes (Intermediate Bond Number)

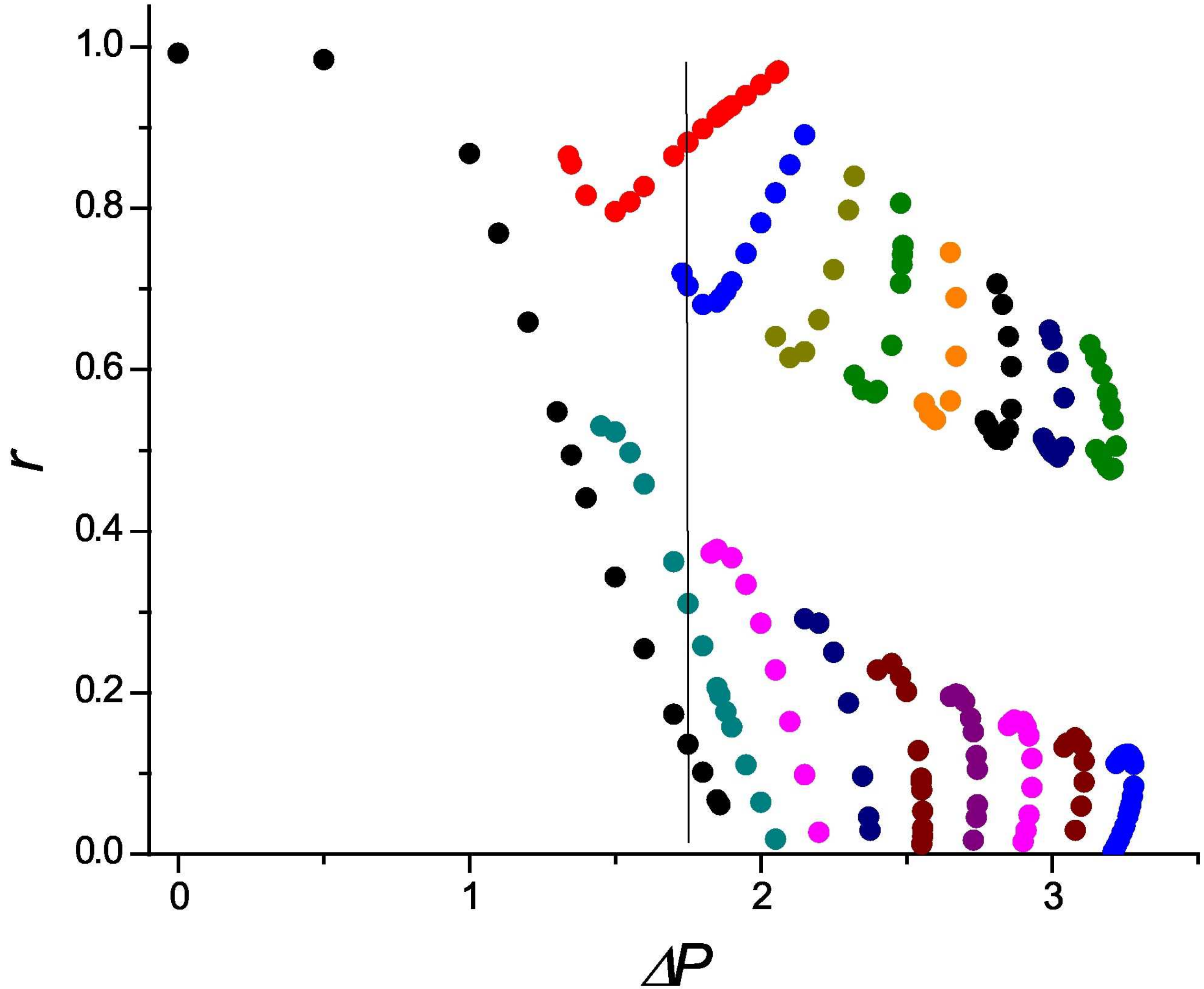
$\theta = 172°, \alpha = 14.3°, B = 0.1$



Gap Width vs. ΔP (Intermediate Bond Number)

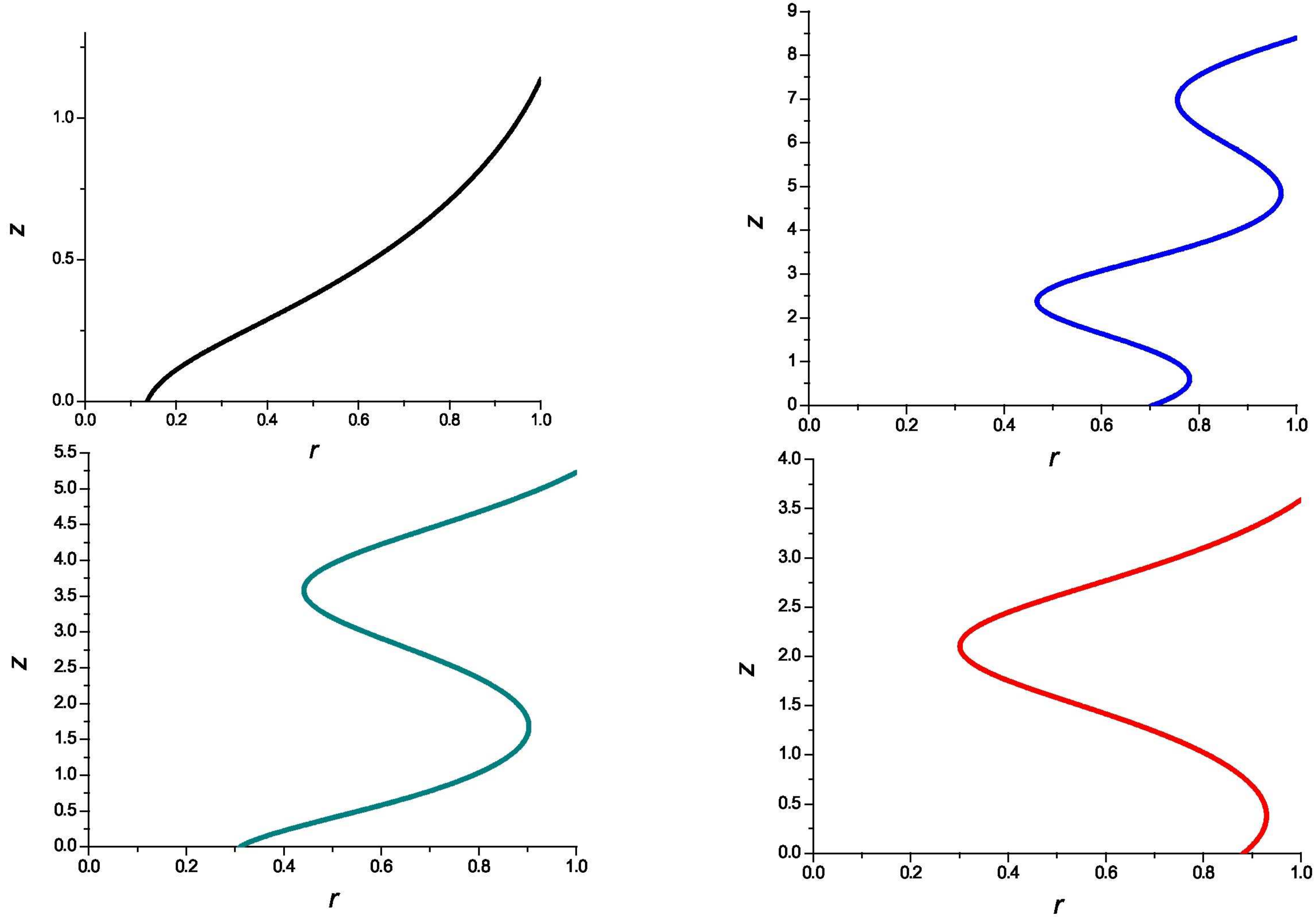
$\theta + \alpha < 180°$

$\theta = 164°$
$\alpha = 14.3°$
$B = 0.1$



Meniscus Shapes (Intermediate Bond Number)

$\theta = 164°$, $\alpha = 14.3°$, $\Delta P = 1.75$, $B = 0.1$, $\alpha + \theta < 180°$



Conclusions

- Meniscus shapes in detached Bridgman growth are determined by the growth and contact angles, the pressure differential, and the Bond number.
- Whether $\theta + \alpha$ is less than or greater than 180° is the determining factor in whether menisci exist at large positive or negative pressure differentials.
- Gap widths have been determined as a function of ΔP for several values of α, θ, and B.
- The largest gap widths are obtained, in general, when ΔP is on the order of γ/r_0.
- The existence of the calculated meniscus shapes will depend on both their static and dynamic stability.